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PBAR DECELERATION IN THE FERMILAB MAIN INJECTOR : TUNE-UP STUDIES WITH PROTON BEAM

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Abstract

In this report we present the results of beam dynamics simulations as well as experiments with protons for deceleration from 150 GeV to 8.9 GeV in the Fermilab Main Injector (MI). The simulations are carried out on two different deceleration schemes: deceleration with a fast recovery MI cycle and with a slow recovery cycle. As a proof of principle we have carried out the first successful deceleration using proton beam in the Main Injector from the Tevatron extraction energy of 150 GeV to the Recycler injection energy of 8.9 GeV.

1 INTRODUCTION

Pbar recycling from the Tevatron collider runs is essential for pbar economy as well as to reach the Run-II luminosity goals[1]. During Run II we plan to provide up to 105 pb-1/week of ppbar luminosity. We need about 1100 mA of pbars per ppbar stores in the Tevatron, 60% of which comes from the pbar source and the remaining 40% should come from recycling. Usually at the end of each ppbar stores in the Tevatron about 70% of the pbar beam will survive and are wasted by dumping them to prepare for the next store. We can re-use the pbars by decelerating them from 1 TeV to 150 GeV in the Tevatron and from 150 GeV to 8.9 GeV in the MI, finally storing and cooling in the newly built Recycler Ring (RR)[2] till the beam is needed for the next collider shot. In this report we investigate the beam deceleration only in the MI.

There are two issues of concern in beam deceleration in MI

1) Longitudinal beam dynamics issues: Typically the beam bunches from the Tevatron at 150 GeV are 3-4 eV-s in 53 MHz rf buckets. But the MI acceptance at transition is only 0.5eV-s. Therefore we can not decelerate beam in the MI from 150 GeV to 8.9 GeV without any further rf manipulations.
2) Transverse beam dynamics issues: The dipoles, (and dipole correctors), quadrupoles (quadrupole correctors) and sextupoles have hysteresis. Hence the up-ramp BH-curves are not same as that of down-ramp. Also, the deceleration BH-curves for quadrupole and sextupoles depends upon the final set values of tune and chromaticity.

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In this connection we have studied two schemes- one with a fast recovery (a 6 sec) MI deceleration cycle (scheme-A) and with a slow recovery (a 20 sec) cycle (scheme-B). In scheme-A the pbar in MI will be decelerated from 150 GeV to 8.9 GeV using 53 MHz (h=588) rf system. At 8.9 GeV the beam is transferred to 2.5 MHz (h=28) rf buckets and finally transferred to the RR. In scheme-B the beam is initially decelerated to about 25 GeV using h=588 system and the adiabatically transferred to h= 28 system and decelerated slowly to 8.9 GeV and finally to the RR. The MI dipole ramps used for these two schemes are shown in Fig.1. Preliminary results of the calculations and experiment carried out on these two schemes are reported previously elsewhere[3].

2 SIMULATIONS

Longitudinal beam dynamics simulations have been carried out using ESME[4] for both the cases discussed

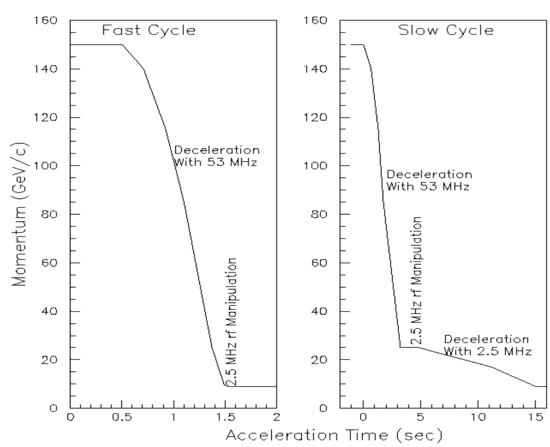

Figure 1. MI Ramps for scheme-A (left) and scheme-B (right) deceleration scenarios.

here by employing the MI parameters from ref.5. We assumed the beam particle distribution is parabolic in dE-dt space, where E is the synchronous energy of the beam particles and t is the time. The 53 MHz bunches from the Tevatron come in a train of four bunches with a bunch separation of twenty one 53 MHz bunches. In our calculations we have assumed that a single bunch from the Tevatron injected in to the MI at 150 GeV.

Simulations have been carried out for both the schemes A and B [3]. The scheme-A results in a significant longitudinal emittance dilution. Further we have also seen beam loss at transition in the MI with scheme-A in contrast with scheme-B. Here we present the results for better of the two schemes. The figure 2 shows the simulated time evolution of phase-space distribution of particles for the scheme-B. The matching rf voltage between Tevatron and MI for 4eV-s beam is about 0.4 MV in the MI 53MHz rf system, which is only 10% of the maximum rf voltage attainable. As a result of this we can afford to decelerate the 53MHz bunches arriving from the Tevatron to 25 GeV(very close to transition energy of 20.49 GeV) in the MI with out any problem. At 25 GeV the beam bunches are transferred to h=28 rf system and beam is decelerated to 8.9 GeV. Unfortunately, we do not have more than 80 kV available from our h=28 rf system. As a results of this we need to decelerate very slowly. The minimum dp/dt during the deceleration between 25 GeV to 8.9 GeV is selected to be -1.7 GeV/c/sec. In the simulation we see very small emittance growth through the entire deceleration process.

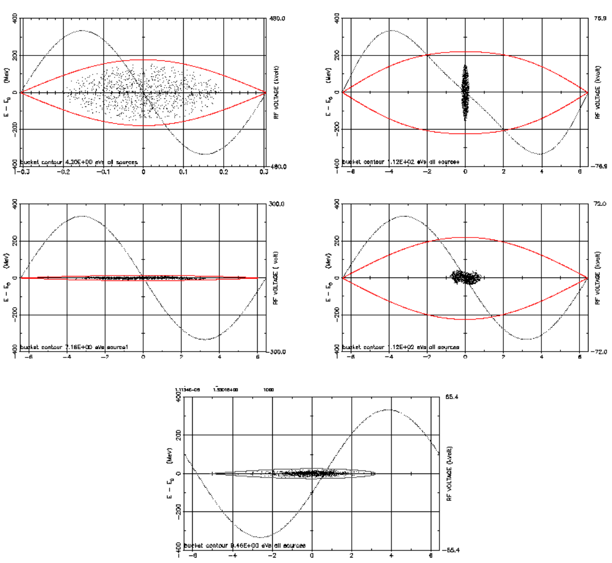

Figure.2: ESME simulations for the slow deceleration ramp. dE vs dϕ for the particle distributions are shown in each display. The closed contours represent buckets and the sinusoidal curve represent the rf voltage wave form. Top left: beam bunch in h=588 bucket at 150 GeV, top right: bunch in h=28 bucket at 25 GeV, middle-row left: bunch in h=28 bucket at 25 GeV after bunch rotation, middle-row right: at 25 GeV after bunch squeezing, bottom: beam in h=28 bucket at 8.9 GeV before injection into the Recycler Ring.

Thus the beam dynamics calculations showed that slow deceleration is more favorable than the fast deceleration from the point of view of transfer efficiency as well as emittance preservation. However, the slow deceleration in the MI needs hardware as well as software developments which are in progress.

3 PROTON DECELERATION IN THE MI FROM 150 GEV TO 8.9 GEV

The beam deceleration experiments are conducted in the MI using protons from the Fermilab Booster and accelerating it to 150 GeV and the ramp developed for the scheme-B. In the absence of 2.5 MHz phase control system, we ended up in conducting all of our deceleration experiments using only the h=588 system.

Table 1: Measured longitudinal emittance on the deceleration ramp.

	Energy (GeV)	Emittance
Flat top	150	0.4 eVs
Back-porch	25	0.4 eVs
RR- Injection enrgy	8.9	0.8 eVs

A controlled beam deceleration in MI is in general not trivial because of the issues discussed earlier. Further, LLRF control needs to be modified to allow phase jump on –ve side of the rf wave at transition. Accelerator control program to correct the orbits, tunes and chromaticities[6] were also modified to accommodate deceleration ramp.

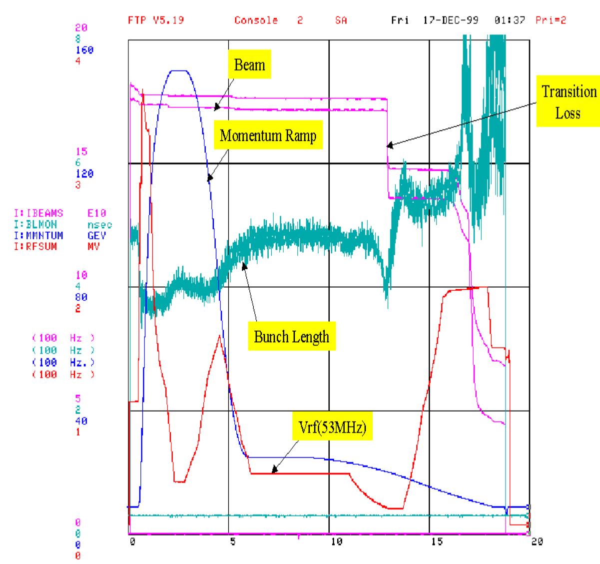

Figure 3: BEAM- MI beam intensity in units of E10, momentum (GeV), bunch length (nsec) and Vrf(53MHz)- rf voltage on 53 MHz rf system (MV) as a function of time (sec).

The Fig.3 represents typical data taken during proton beam deceleration in the MI with scheme-B (slightly modified, and deceleration carried out with 53MHz system) after correcting the orbit and the magnet hysteresis up to about 15 GeV. The early part of the data represents the beam acceleration from 8.9 GeV to 150 GeV. The data shown contains Beam (scale: 0 – 20E10), Momentum P(scale:0 to 160 GeV/c) Bunch length (scale: 0-8 nsec) and voltage on 53 MHz rf system during the operation (scale: 0 to 4 MV). Almost 100% of the beam survive from 150GeV (flat-top) to 20.49 GeV(down) (transition energy). Below the transition energy 85% of the beam survive. We saw another 50% beam loss at about 13.5 GeV leaving finally about 40% of the beam to 8.9GeV. Table 1 shows the measured longitudinal emittance of the beam for the entire process. We have used bunch length monitor data and correct phase angle at 8.9 GeV, 150 GeV, and at 25 GeV to estimate the longitudinal emittance.

The data clearly shows that very small emittance growth from 150 GeV to transition energy. At transition, however, we observe beam loss. This beam loss can be understood as follows: The non-adiabatic time, Tc, for the case studied here is about 20msec. The maximum $(dp/p)_{99\%}$ corresponding to the MI admittance of 0.5 eVs [1] is 0.9%. But, the $(dp/p)_{99\%}$(beam) corresponding to the bunch length of 4 nsec (from the figure 3) near transition energy is about 1.1%. Hence, the beam loss seen near transition is natural. About 15% beam loss is observed under present conditions. This problem can be eliminated if we use 2.5 MHz rf buckets instead of 53 MHz rf for deceleration through the transition. Second beam loss occurring at 13.5 GeV is not fully understood at this time. Our calculations shows that it is not due to limited rf bucket area. The actual cause may be arising from the magnet power supplies switch off as we decelerate the beam which was not emphasized so far during the beam operation.

A simple extrapolation of the results of the experiment to a case of deceleration with h=28 system (as proposed in ref. 2) with about 60 kV of rf voltage suggests that one should be able to decelerate a bunch with longitudinal emittance as big as 7 eV-sec through MI transition without any beam loss.

We have also measured transverse emittance using flying wires of MI. Data showed no transverse emittance growth during the deceleration.

In summary, we have conducted series of pbar deceleration simulations as well as experiments using proton beam in the MI. This effort was the first attempt of proof of principle for decelerating the beam in the MI. We were able to successfully decelerate the beam from 150 GeV to 8.9 GeV with about 100% till transition energy and 85% beyond. This result is consistent with our longitudinal beam dynamics simulations. But, needs further improvements, which are being working on.

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